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STRENGTH AND DURABILITY OF CONCRETE MADE WITH TYPE 10 CEMENTS USED IN ONTARIO

MATERIALS INFORMATION
ENGINEERING MATERIALS OFFICE

STRENGTH AND DURABILITY OF CONCRETE MADE WITH TYPE 10 CEMENTS USED IN ONTARIO

by:

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SUMMARY

This paper describes a laboratory investigation of concrete to determine the effect of the various brands of Type 10 portland cement with and without interground limestone on the strength and freeze--thaw durability. Two classes of concrete and two combinations of aggregates were used in the investigations.

It has been found that there is a variation in the strength of concrete made with the various cements. The limestone addition increases the concrete strength. Concrete made with each of the cements had a very good resistance to freezing and thawing in water. However, there was a considerable variation in the resistance to salt scaling.

Keywords: Type 10 portland cement, interground limestone, concrete, compressive strength, freeze-thaw resistance, salt scaling.

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STRENGTH AND DURABILITY OF CONCRETES MADE WITH TYPE 10 CEMENTS USED IN ONTARIO

INTRODUCTION

In recent years, the Ontario Ministry of Transportation and Communications (MTC) has experienced an increase in salt scaling of exposed concrete particularly on barrier walls on structures. Some of the concrete showing scaling appears to be good quality concrete with a low water/cement ratio, good quality aggregates and a reasonable air voids system. In addition, concrete mixes made to the same design specifications have at times shown significant differences in strength across the province.

The Ministry is currently planning to introduce performance specifications for concrete strength. The Ministry would require the ingredients of the concrete to come from a choice of designated sources, and would control the air content and slump in the plastic concrete, but would not control the mix proportions used or the compatibility of the various materials used.

For the above reasons, the Ministry decided to investigate the effect of varying the brand of cement used on the strength and freeze-thaw durability of a number of standard concrete mixes. The Ministry allows the use of Portland cements containing up to 5% interground limestone and where possible similar cements with and without the limestone addition were tested.

OBJECTIVES

The objectives of this project were to determine:

i) differences between the strength producing properties of CSA Type 10 (ASTM Type I) cements approved by the Ministry using two different aggregates and two strength classes (20 MPa and 30 MPa concrete)

ii) differences between the effects of the cements on the durability of concrete in relation to freezing and thawing and salt scaling resistance.

iii) whether interground limestone in the cement has a beneficial/detrimental effect on the strength and durability of concrete

iv) the relative performance of the cements and to relate this to other intrinsic properties associated with each cement

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MATERIALS USED IN THE TEST PROGRAM

CEMENTS

Type 10 Portland cements from fourteen sources (mills) were included in the program. Each source was represented by a single sample, generally obtained at ready mix concrete plants. For those cements not being used on Ministry contracts at the time, samples were obtained directly from the cement mills. Samples with and without interground limestone were obtained from two manufacturers.

Table A identifies the cements by sample number. The physical and chemical properties of the cements are shown in Tables B1, B2, and C1, C2 and C3 respectively.

AGGREGATES

Two combinations of aggregates were used for the testing of the cements. Combination A consisted of:

Coarse Aggregate - Crushed dolomitic limestone (19 mm nominal maximum size)

Fine Aggregate - Natural sand

Combination B consisted of:

Coarse Aggregate - Partly crushed gravel (19 mm nominal maximum size)
Fine Aggregate - Natural sand *

ADMIXTURES

a) Air Entraining Admixture - a sulphonated hydrocarbon complying with the requirements of OPSS Form 1303[1] (A Provincial Standard - similar to ASTM C260).

b) Water Reducer - a lignosulphonate normal setting admixture meeting the requirements of OPSS Form 1303[1] for Type WN, (similar to ASTM C494 Type A). It was used at a dosage of 440 mL per 100 kg cement.

CONCRETE MIXES AND FABRICATION OF SPECIMENS

Each cement was tested in two series of mixes using each of the two

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* Source of natural sand for combination B was different than for combination A.

combinations of aggregates. One of the series was a 20 MPa class air entrained concrete made with a cement content of 310 kg/m3 and the other was a 30 MPa class air entrained concrete made with a cement content of 355 kg/m3.[2] All mixes were proportioned to produce a slump of 80 ± 10 mm and an air content of 6 ± 1.0% as measured by the pressure meter. The mix proportions together with the test results on the plastic concretes are shown in Tables D1 to D4. The brand of cement was the only variable in the mixes for each series.

The concrete was mixed in a pan type mixer. A 50 L batch of concrete was made with each of the cements for each aggregate combination and series of mixes. Each batch was used to fabricate four 100 mm x 200 mm compressive strength cylinders for each of four test ages, three 75 mm x 100 mm x 400 mm freeze/thaw prisms and two 75 mm x 300 mm x 300 mm salt scaling slabs (in accordance with ASTM C192).[3]

CURING AND TESTING OF SPECIMENS

For the compressive strengths, the cylinders were cured and tested in accordance with CSA A23.2-3C,[4] 9C[5].

For the freeze/thaw prisms, the specimens were cured and tested in accordance with ASTM C666-84,[6] Proc. A. Where freeze/thaw cycle tests could not begin after 14d the specimens were wrapped in plastic bags and stored at -18 ± 2°C until testing could commence. The length change, weight change and dynamic modulus were calculated taking the length, weight and dynamic modulus after removal from the moulds as the base.

For the salt scaling slabs, the test was carried out in accordance with ASTM C672-84[7] with the following modifications:

1) Precast dykes were secured with a mortar mix to a matching recess cast along the perimeter of the slab and sealed with an epoxy.

2) Where salt scaling tests could not begin after 28d, the slabs were wrapped in plastic bags and stored at -18 ± 2°C until testing could commence.

3) The deicing agent was a 3% sodium chloride solution.[8]

4) The cumulative mass loss was determined after each 5 cycles of freezing and thawing for each slab and averaged for the pairs. The mass loss is the dry mass of the flaked off concrete.

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DISCUSSION OF TEST RESULTS

CHEMICAL PROPERTIES OF CEMENTS

All the cements complied with the requirements of OPSS Form 1301 [9] (CSA Standard CAN 3-A5-M83).

The presence of interground limestone in the cement was calculated from the following formula:

$$\% \text{ Carbonate Addition} = \frac{[\text{L.O.I. } (1050^{\circ}\text{C}) - \text{L.O.I. } (550^{\circ}\text{C})]}{100 \times \text{Limestone (L.O.I.)}}$$

where L.O.I. (1050°C) is the loss on ignition of the cement at 1050°C
L.O.I. (550°C) is the loss on ignition of the cement at 550°C
Limestone (L.O.I.) is the loss on ignition of the limestone used in the manufacture of the cement. (Typically 38-42%)

The theoretical assumption (based on information obtained from the cement manufacturers) is that a % carbonate addition (calculated using the above formula) greater than 1.5 indicates interground limestone in the cement. On the basis of the test results from Table C, cements A, B, C, C2, F, G, J and J2 contain interground limestone, all below the maximum allowance of 5%.

PHYSICAL TESTS OF CEMENTS

All the cements complied with the requirements of OPSS Form 1301 (CSA Standard CAN 3-A5-M83).

The 28d compressive strengths of the mortar cubes for the cements tested had a range of 11.7 MPa. This range was of the same magnitude as the difference amongst the cements in 28d compressive strengths for the concrete mixes. However the relative ranking of the cements based on the 28d compressive strengths of the mortar cubes differed significantly when compared with the relative ranking based on the 28d compressive strengths of the concrete mixes.

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CONCRETE COMPRESSIVE STRENGTHS

The compressive strength test results on the concrete mixes are illustrated in Figures 1A, 1B, 1C and 1D. The range in 28d compressive strengths amongst all concretes for the 20 MPa and 30 MPa mixes was 10.3 MPa and 17.0 MPa respectively for aggregate A and 11.0 MPa and 10.5 MPa respectively for aggregate B. The relative performance of each cement was consistent for each of the four mixes.

The average 28d compressive strengths of all concretes for the 20 MPa mixes were 40.3 MPa for aggregate A and 34.6 MPa for aggregate B. For the 30 MPa mixes the averages were 45.6 MPa for aggregate A and 38.5 MPa for aggregate B. Thus, at first glance, the 28d compressive strengths for aggregate A were 14.1% and 18.4% greater than for aggregate B for 20 MPa and 30 MPa concrete respectively.

Examination of the results of the air void system by linear traverse (Table F) revealed an air content approximately 0.7% and 1.1% greater for the concretes with aggregate B versus aggregate A for 20 MPa and 30 MPa concrete respectively. For those concretes tested with both aggregates and examined by linear traverse, the average 28d compressive strengths for the 20 MPa mixes were 40.0 MPa for aggregate A and 34.3 MPa for aggregate B. For the 30 MPa mixes the averages were 45.4 MPa for aggregate A and 37.9 MPa for aggregate B. By adjusting the compressive strengths of the concrete mixes (5% for the 20 MPa and 6% for the 30 MPa for each 1% difference in the air content of the hardened concrete)[10], the net strength gain for aggregate A versus B is reduced to 12 % regardless of the class of concrete.

Examination of the compressive strengths for concretes made with cements from the same source with/without the interground limestone (i.e. C1, C2, J1 and J2) indicates that those cements with the carbonate addition have a 28d compressive strength 6% (4.5 - 8.8%) greater than the same cements without carbonate addition and a 91d compressive strength 7.6% (4.4 - 10.2%) greater. Review of the mix proportions on the fresh concrete indicates that the water requirements to obtain the required slump were lower in all cases with the concretes made with the cements (C1, C2, J1 and J2) containing the carbonate addition.

FREEZE THAW TESTS

The results of the freeze thaw tests are shown in Table E. All concretes performed well. After 300 cycles the lowest relative dynamic modulus was 93.5, the highest change in length was +0.033% and the largest weight change was -3.81%.

It is notable that the spread in performance amongst all concretes was closer for all three measured parameters for concretes prepared with aggregate B versus aggregate A. One factor that probably contributed to the better performance with aggregate B was the higher air content and lower spacing factor (Table F) in the hardened concrete with the concretes using aggregate B.

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SALT SCALING TESTS

Although the salt scaling tests have been largely completed, the test results are not presented in this report. Concrete made with some of the cements scaled more than 0.8 kg/m^2[11](the Ministry acceptance guideline).

It is possible that the excessive scaling is due to an inadequate air void system at the surface exposed to scaling or the test method requires more than a single test to produce reliable test results. The two factors are being investigated and an assessment of the relative salt scaling resistance of the various concretes will be made when this investigation is completed.

CONCLUSIONS & RECOMMENDATIONS

here is a considerable variation in the strength of concrete made with the various cements. The difference between the lowest and the highest strength was 10.3 MPa and 17.0 MPa for the 20 and 30 MPa class concrete, respectively, for mixes with the dolomitic limestone aggregate, and 11.0 MPa and 10.5 MPa for the 20 and 30 MPa class concrete respectively for mixes with the gravel aggregate.

Indications are that the addition of interground limestone is beneficial to the strength of concrete.

Concrete made with each of the cements had a very good resistance to freezing and thawing in water. The lowest relative dynamic modulus of elasticity at 300 cycles was 93.5%. The addition of interground limestone appears to have a neutral effect.

The salt scaling tests have been largely completed. Some concretes showed an excessive amount of scaling. However, it is thought that this may be related to an inadequate air void system in the concrete at the surface and/or the precision of the test itself. The effect of these factors in the salt scaling performance will be investigated before the relative performance of the various cements is determined.

REFERENCES

1. O.P.S.S. Form 1303 (December 1983), Material Specification for Air Entraining and Chemical Admixtures for Portland Cement Concrete, Ontario Provincial Standard Specifications, Volume I.

2. O.P.S.S. Form 1350 (December 1983), Material Specification for Concrete (Materials and Production), Ontario Provincial Standard Specifications, Volume I.

3. A.S.T.M. C192-81, Standard Method of Making and Curing Concrete Test Specimens in the Laboratory.

4. C.S.A. A23.2-3C, Making and Curing Concrete Compression and Flexural Test Specimens; Canadian Standards Association, Methods of Test for Concrete, CAN3-A23.2-M77.

5. C.S.A. A23.2-9C, Compressive Strength of Cylindrical Concrete Specimens; Canadian Standards Association, Methods of Test for Concrete, CAN-A23.2-M77.

6. A.S.T.M. C666-84, Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing.

7. A.S.T.M. C672-84, Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals.

8. O.P.S.S. Form 2502 (December 1983) Material Specification for Sodium Chloride, Ontario Provincial Standard Specifications, Volume I.

9. O.P.S.S. Form 1301 (September 1984) Material Specification for Hydraulic Cementing Materials, Ontario Provincial Standard Specifications, Volume I.

10. Bloem, D.L., "Air Entrainment in Concrete," Pamphlet N.S.G. and N.R.M.C.A. (August 1950) 30p.

11. O.P.S.S. Form 1351 (December 1984) Material Specification for Components for Precast Reinforced Concrete Catch Basins, Manholes, Ditch Inlets and Valve Chambers, Ontario Provincial Standard Specifications, Volume I.

TABLE A
IDENTIFICATION KEY TO THE TYPE 10 CEMENTS TESTED

I. D. *	SOURCE	MTC LAB SAMPLE *
A	Contract	84-L-12
B	Contract	84-L-21
C	Contract	84-L-10
C1	Plant	84-L-07*
C2	Plant	84-L-08
D	Contract	84-L-15
E	Contract	84-L-20
F	Contract	84-L-22
G	Plant	84-L-19
H	Contract	84-L-17
I	Plant	84-L-29
J	Contract	84-L-27
J1	Plant	84-L-26*
J2	Plant	84-L-25
K	Contract	84-L-13
L	Plant	85-L-02
M	Plant	84-L-23
N	Plant	85-L-01

NOTES:

* Made to comply with ASTM C150-83a.

TABLE B1
RESULTS OF PHYSICAL TESTS ON TYPE 10 CEMENTS

I. D. #	RELATIVE DENSITY AS TESTED BY				FINENESS		
	MTC (LeChatelier Flask)	ST.LAWRENCE CEMENT (Air Pycnometer)	CANADA CEMENT LAFARGE (Air Pycnometer)	CANADA CEMENT LAFARGE (He)	PASS 45um SIEVE % (MTC)	% (CCL)	AIR PERMEABILITY m^2/kg (BLAINE)
A	3.08	3.11	3.13	3.12	82.9	84.5	371.5
B	3.11	3.13	3.14	-	93.5	92.0	375.7
C	3.10	3.14	3.15	3.11	80.9	85.0	380.5
C1	3.11	-	3.16	-	85.9	86.0	402.7
C2	3.11	3.14	3.12	-	84.7	88.5	364.2
D	3.11	3.14	3.14	-	94.8	93.0	397.9
E	3.11	3.14	3.17	-	86.8	86.0	408.3
F	3.09	3.10	3.14	-	91.1	91.0	381.2
G	3.12	3.13	3.13	-	86.0	88.5	373.2
H	3.09	3.09	3.12	-	85.1	87.5	386.8
I	3.06	3.05	3.06	-	94.3	95.1	411.4
J	3.09	3.09	3.12	-	88.8	89.0	387.8
J1	3.08	3.10	3.15	-	91.6	90.0	397.8
J2	3.10	3.08	3.13	-	91.3	90.5	398.2
K	3.09	3.13	3.15	3.11	89.2	90.5	390.2
L	3.11	3.11	3.14	-	95.8	92.5	404.8
M	3.11	3.16	3.15	-	87.1	88.0	348.6
N	3.17	3.13	3.20	-	93.2	93.0	373.6

TABLE B2
RESULTS OF PHYSICAL TESTS ON TYPE 10 CEMENTS

I. D. *	SOUNDNESS	SET TIME	FALSE SET	AIR CONTENT	COMPRESSIVE SRENGTH		
	(%exp.)	(min)	PASTE METHOD (%)	MORTAR (%)	3DAY (Mpa)	7DAY (Mpa)	28DAY (Mpa)
A	0.194	95	51.8	9.99	20.7	25.1	31.7
B	0.262	100	72.4	8.03	23.4	25.4	34.0
C	0.110	100	66.7	10.40	21.6	24.3	28.5
C1	0.158	80	70.0	N.S.M	23.6	27.9	32.6
C2	0.088	95	57.7*	8.67	22.5	25.8	31.3
D	0.126	120	80.3	9.96	25.0	28.7	37.1
E	0.124	95	57.1	7.56	17.9	21.5	30.6
F	0.062	105	62.9	10.14	24.1	27.3	32.6
G	0.018	130	51.7	9.62	17.9	23.2	28.9
H	0.086	90	59.4	8.88	20.3	22.9	28.7
I	0.064	90	64.3	8.51	24.0	26.8	36.3
J	0.130	80	80.0	9.42	20.6	26.7	33.3
J1	N.S.M.	71	70.6	9.55	21.6	29.3	40.2
J2	0.140	81	80.7	9.06	22.0	28.8	34.4
K	0.048	95	74.2	9.17	20.1	25.4	34.0
L	0.096	180	69.0	7.72	23.4	26.2	32.2
M	0.044	130	66.1	9.06	19.2	25.0	31.7
N	0.048	190	80.0	7.67	18.6	28.6	39.1

NOTES:

1) All tests carried out in accordance with CSA Standard CAN 3-A5-M83
2) (He) - Helium Pycnometer
3) N.S.M. - Not Sufficient Material
4) * 57.7% is a remix value; origional value was 34.4%
5) O P.S.S. (MTC) Form 1301 Requirements for Type 10 Cement:

Fineness: Min. 72%
Soundness: Max. 1.0%
Set Time: Min. 45, Max. 360 minutes
False Set: Min. 50%
Comp. Strength: 3d Min. 12.5Mpa.; 7d Min. 18.0 Mpa.; 28d Min. 26.5 Mpa.

TABLE C1
RESULTS OF CHEMICAL TESTS ON TYPE 10 CEMENTS

I. D. #	LOSS ON IGNITION (%)			INSOLUBLE RESIDUE (%)	TRICALCIUM ALUMINATE (C3A) (%)	SULPHUR TRIOXIDE (SO3) (%)	SULPHATE EXP. (%)
	MTC (1050°C)	ST. MARYS (550°C)	ST. MARYS (1000°C)				
A	2.56	1.43	2.53	0.63	12.96	3.69	0.009
B	2.75	1.49	2.86	0.28	6.81	3.64	0.017
C	2.14	0.94	2.01	0.92	13.17	3.22	-
C1	0.90	0.75	0.96	0.37	12.29	3.02	-
C2	1.77	1.14	2.18	0.67	13.22	3.23	-
D	1.98	1.32	1.82	0.23	8.15	2.99	-
E	1.62	1.37	1.88	0.11	7.00	2.74	-
F	2.63	1.08	2.66	0.50	9.02	3.17	-
G	2.44	1.48	2.57	0.66	8.00	3.28	-
H	1.75	1.55	1.87	0.20	12.84	3.14	-
I	2.20	1.87	2.31	0.22	12.65	4.10	0.014
J	2.77	1.18	3.03	0.46	10.32	2.89	-
J1	1.24	1.04	1.58	0.35	10.30	2.94	-
J2	2.79	1.17	2.98	0.38	9.26	2.68	-
K	1.66	1.51	1.83	0.16	9.56	2.80	-
L	1.36	1.19	1.70	0.33	7.80	3.10	-
M	1.75	1.14	1.36	0.47	9.30	2.96	-
N	0.77	0.80	0.92	0.33	8.08	2.61	-

TABLE C2
RESULTS OF CHEMICAL TEST ON TYPE 10 CEMENTS

I. D. •	MAGNESIUM OXIDE (MgO) (%)	SODIUM OXIDE (Na2O)		POTASSIUM OXIDE (K2O)		ALKALI CONTENT	
		(MTC) (%)	(CCL) (%)	(MTC) (%)	(CCL) (%)	(MTC) (%)	(CCL) (%)
A	2.48	0.25	0.24	0.99	1.04	0.90	0.92
B	3.89	0.40	0.45	0.85	0.90	0.96	1.04
C	2.55	0.24	0.22	1.16	1.24	1.00	1.04
C1	2.48	0.23	0.27	1.14	1.16	0.98	1.03
C2	2.43	0.23	0.24	1.07	1.18	0.93	1.02
D	4.17	0.16	0.17	0.83	0.82	0.71	0.71
E	3.65	0.41	0.47	0.39	0.40	0.67	0.73
F	2.48	0.30	0.33	0.92	1.00	0.91	0.99
G	2.22	0.28	0.30	0.81	0.91	0.81	0.90
H	2.32	0.15	0.18	1.03	1.10	0.83	0.90
I	2.00	0.17	-	1.10	-	0.89	-
J	2.20	0.30	0.31	0.58	0.65	0.68	0.74
J1	2.41	0.34	0.33	0.68	0.73	0.79	0.81
J2	2.44	0.30	0.31	0.62	0.66	0.71	0.74
K	1.91	0.16	0.16	0.80	0.83	0.69	0.71
L	3.47	0.24	0.18	1.06	1.10	0.94	0.90
M	3.23	0.22	0.20	0.80	0.80	0.75	0.73
N	3.31	0.25	0.27	0.43	0.44	0.53	0.56

TABLE C3
RESULTS OF CHEMICAL TEST ON TYPE 10 CEMENTS

I. D. #	SILICON DIOXIDE (SiO2) (%)	ALUMINUM OXIDE (Al2O3) (%)	FERRIC OXIDE (Fe2O3) (%)	CALCIUM OXIDE (CaO) (%)	FREE CALCIUM OXIDE (%)	CARBONATE ADDITION (%)
A	19.42	6.38	2.34	61.80	0.80	3.19
B	18.96	4.59	3.17	62.02	1.80	3.30
C	20.03	6.36	2.18	62.20	0.59	2.82
C1	20.91	6.08	2.26	62.98	0.83	0.55
C2	20.50	6.30	2.06	62.84	0.55	2.74
D	20.27	4.69	2.53	62.44	0.71	1.32
E	21.58	4.37	2.71	62.77	0.73	1.21
F	20.22	4.96	2.44	62.98	0.57	4.16
G	21.25	4.85	2.87	62.02	0.57	2.87
H	20.68	6.26	2.22	62.57	1.83	0.82
I	19.84	6.17	2.19	62.22	1.25	1.13
J	20.86	5.57	2.63	62.00	0.82	4.63
J1	21.40	5.69	2.83	61.84	0.51	1.35
J2	20.62	5.25	2.75	62.61	0.98	4.53
K	21.01	5.41	2.83	63.32	0.94	0.84
L	20.88	4.61	2.73	62.66	0.97	1.34
M	20.92	5.21	2.67	62.29	0.36	0.58
N	21.10	5.24	3.44	62.96	0.13	0.05

NOTES:

1) All tests carried out in accordance with CSA Standard CAN 3-A5-M83 with the exception of
   (i) Free Calcium Oxide test which was carried out in accordance with ASTM C114-83a and
   (ii) Carbonate Addition which was carried out by St. Marys Cement Co. using
   % Carbonate Addition = [L.O.I.(1050°C)-L.O.I.(550°C)]/[100xLIMESTONE(L.O.I.)]
2) Alkali Content (%) = (Na2O + 0.658K2O)
3) O.P.S.S. (MTC) Form 1301 Requirements for Type 10 Cement:

   L.O.I. (MTC)(1050°C): Max. 3.5%
   Insoluble Residue: Max. 1.0%
   Sulphur Trioxide: (i) C3A>7.5%, Max. 3.5%; (ii) C3A ≤7.5%, Max. 3.0%
   Sulphate Expansion: Max. 0.020% @ 14 days
   Magnesium Oxide: Max. 5.0%

TABLE D1
CONCRETE MIX PROPORTIONS AND TEST RESULTS ON FRESH CONCRETE
20 Mpa CLASS CONCRETE ; AGGREGATE COMBINATION 'A'

I. D. *	LAB MIX *	BATCH QUANTITIES						TEST RESULTS - FRESH CONCRETE						
		FINE AGG. (kg)	COARSE AGG. (kg)	CEMENT (kg)	WATER (TOTAL) (kg)	WR (ml)	AEA (ml)	SLUMP (mm)	AIR CONTENT (%)	DENSITY (kg/m^3)	YIELD (m^3)	CEMENT CONTENT (kg/m^3)	EFF. W/C RATIO (tot. cement)	EFF. W/C* RATIO (cem.pass.45µm)
A	L-810/84	39.3	53.7	15.5	8.75	68.2	1.7	70	6.6	2343	0.0500	310.0	0.494	0.595
B	L-841/84	39.3	53.7	15.5	8.25	68.2	1.0	75	6.6	2371	0.0490	316.3	0.471	0.500
C	L-817/84	39.3	53.7	15.5	9.00	68.2	1.2	70	6.4	2336	0.0503	308.2	0.510	0.630
C1	L-813/84	39.3	53.7	15.5	9.25	68.2	1.2	75	6.0	2343	0.0503	308.2	0.526	0.612
C2	L-827/84	39.3	53.7	15.5	8.40	68.2	1.0	80	6.5	2333	0.0501	309.4	0.471	0.556
D	L-819/84	39.3	53.7	15.5	8.65	68.2	3.1	75	6.9	2336	0.0502	308.8	0.487	0.514
E	L-849/84	39.3	53.7	15.5	8.90	68.2	2.5	75	5.5	2382	0.0493	314.4	0.503	0.548
F	L-831/84	39.3	53.7	15.5	7.80	68.2	1.9	75	6.4	2357	0.0493	314.4	0.432	0.474
G	L-839/84	39.3	53.7	15.5	8.40	68.2	1.2	75	5.8	2386	0.0490	316.3	0.471	0.548
H	L-835/84	39.3	53.7	15.5	8.90	68.2	1.9	70	6.0	2357	0.0502	308.6	0.503	0.591
I	L-706/85	39.3	53.7	15.5	8.15	68.2	0.5	75	6.7	2321	0.0503	308.2	0.455	0.482
J	L-866/84	39.3	53.7	15.5	9.20	68.2	2.5	85	5.5	2357	0.0499	310.6	0.523	0.588
J1														
J2														
K	L-815/84	39.3	53.7	15.5	8.85	68.2	1.2	70	5.4	2361	0.0497	311.9	0.500	0.560
L	L-716/85	39.3	53.7	15.5	8.85	68.2	1.3	85	6.3	2336	0.0502	308.8	0.500	0.522
M	L-837/84	39.3	53.7	15.5	9.10	68.2	2.1	70	6.6	2350	0.0499	310.6	0.516	0.592
N	L-712/85	39.3	53.7	15.5	9.15	68.2	1.9	85	6.5	2347	0.0504	307.5	0.519	0.557

NOTES:

1) All tests carried out in accordance with CSA Standard CAN 3-A23.2-M77.

* Effective water/cement ratio calculated using only amount of cement passing 45µm sieve.

TABLE D2
CONCRETE MIX PROPORTIONS AND TEST RESULTS ON FRESH CONCRETE
30 Mpa CLASS CONCRETE ; AGGREGATE COMBINATION 'A'

I. D. •	LAB MIX •	BATCH QUANTITIES						TEST RESULTS - FRESH CONCRETE						
		FINE AGG. (kg)	COARSE AGG. (kg)	CEMENT (kg)	WATER (TOTAL) (kg)	WR (ml)	AEA (ml)	SLUMP (mm)	AIR CONTENT (%)	DENSITY (kg/m^3)	YIELD (m^3)	CEMENT CONTENT (kg/m^3)	EFF. W/C RATIO (tot. cement)	EFF. W/C• RATIO (cem.pass.45µm)
A	L-811/84	37.3	53.7	17.75	9.00	78.3	2.1	70	5.9	2357	0.0500	356.0	0.444	0.535
B	L-842/84	37.3	53.7	17.75	8.60	78.3	1.1	75	6.2	2379	0.0494	358.9	0.421	0.451
C	L-818/84	37.3	53.7	17.75	9.20	78.3	1.4	90	6.5	2357	0.0501	355.3	0.455	0.563
C1	L-814/84	37.3	53.7	17.75	9.80	78.3	1.4	85	5.6	2350	0.0505	352.5	0.489	0.569
C2	L-828/84	37.3	53.7	17.75	8.85	78.3	1.1	80	5.6	2350	0.0501	355.3	0.435	0.514
D	L-820/84	37.3	53.7	17.75	9.05	78.3	2.1	80	6.4	2357	0.0500	356.0	0.447	0.471
E	L-850/84	37.3	53.7	17.75	8.80	78.3	3.6	75	5.5	2389	0.0492	361.8	0.433	0.498
F	L-832/84	37.3	53.7	17.75	8.55	78.3	2.1	80	6.2	2350	0.0499	356.7	0.419	0.459
G	L-840/84	37.3	53.7	17.75	8.20	78.3	1.4	75	6.0	2361	0.0496	358.9	0.399	0.464
H	L-836/84	37.3	53.7	17.75	9.20	78.3	2.1	70	6.0	2350	0.0502	354.5	0.455	0.535
I	L-707/85	37.3	53.7	17.75	8.30	78.3	0.5	75	5.5	2375	0.0493	361.1	0.416	0.441
J	L-867/84	37.3	53.7	17.75	9.00	78.3	4.3	80	6.3	2343	0.0503	353.9	0.444	0.500
J1														
J2														
K	L-816/84	37.3	53.7	17.75	9.00	78.3	2.1	85	5.5	2368	0.0497	358.2	0.444	0.498
L	L-717/85	37.3	53.7	17.75	8.90	78.3	1.4	90	6.2	2329	0.0505	352.5	0.438	0.458
M	L-838/84	37.3	53.7	17.75	8.55	78.3	2.1	70	6.0	2350	0.0502	354.5	0.455	0.522
N	L-813/85	37.3	53.7	17.75	9.10	78.3	2.8	75	5.4	2375	0.0496	358.9	0.449	0.482

NOTES:

1) All tests carried out in accordance with CSA Standard CAN 3-A23.2-M77.

• Effective water/cement ratio calculated using only amount of cement passing 45µm sieve.

TABLE D3

CONCRETE MIX PROPORTIONS AND TEST RESULTS ON FRESH CONCRETE

20 Mpa CLASS CONCRETE; AGGREGATE COMBINATION 'B'

I. D. *	LAB MIX *	BATCH QUANTITIES						TEST RESULTS - FRESH CONCRETE						
		FINE AGG. (kg)	COARSE AGG. (kg)	CEMENT (kg)	WATER (TOTAL) (kg)	WR (ml)	AEA (ml)	SLUMP (mm)	AIR CONTENT (%)	DENSITY (kg/m^3)	YIELD (m^3)	CEMENT CONTENT (kg/m^3)	EFF. W/C RATIO (tot. cement)	EFF. W/C* RATIO (cem.pass.45µm)
A	L-708/85	34.5	56.8	15.5	8.30	68.2	1.0	75	6.3	2286	0.0503	307.5	0.4969	0.599
B	L-752/85	34.5	56.8	15.5	8.15	68.2	1.0	85	6.8	2261	0.0508	305.1	0.4871	0.521
C	L-750/85	34.5	56.8	15.5	8.45	68.2	1.0	90	6.5	2286	0.0504	307.5	0.5040	0.623
C1	L-863/84	36.3	56.8	15.5	8.80	68.2	1.2	80	6.3	2296	0.0511	303.3	0.5290	0.616
C2														
D	L-732/85	34.5	56.8	15.5	8.50	68.2	1.9	75	5.6	2304	0.0501	309.4	0.5097	0.538
E	L-742/85	34.5	56.8	15.5	8.10	68.2	2.5	75	5.4	2314	0.0497	311.9	0.4838	0.557
F	L-700/85	34.5	56.8	15.5	8.00	68.2	1.2	75	6.4	2286	0.0502	308.8	0.4773	0.524
G	L-702/85	34.5	56.8	15.5	7.95	68.2	1.0	75	6.1	2307	0.0497	311.9	0.4742	0.551
H	L-734/85	34.5	56.8	15.5	8.50	68.2	1.9	80	6.8	2264	0.0509	304.5	0.5097	0.599
I	L-704/85	34.5	56.8	15.5	8.40	68.2	0.2	75	6.4	2282	0.0505	306.9	0.5034	0.534
J	L-710/85	34.5	56.8	15.5	8.50	68.2	3.1	75	5.6	2304	0.0501	309.4	0.5129	0.578
J1	L-857/84	36.3	56.8	15.5	8.70	68.2	3.5	80	6.7	2282	0.0514	301.6	0.5225	0.570
J2	L-855/84	36.3	56.8	15.5	7.70	68.2	2.5	70	5.5	2307	0.0504	307.5	0.4580	0.502
K	L-740/85	34.5	56.8	15.5	8.20	68.2	1.2	75	6.0	2300	0.0500	310.0	0.4903	0.550
L	L-718/85	34.5	56.8	15.5	8.40	68.2	1.3	85	6.4	2271	0.0507	305.7	0.5033	0.525
M	L-757/85	34.5	56.8	15.5	7.95	68.2	1.3	75	6.8	2261	0.0508	305.1	0.4742	0.544
N	L-714/85	34.5	56.8	15.5	8.05	68.2	2.5	75	6.4	2314	0.0496	312.5	0.4806	0.516

NOTES:

1) All tests carried out in accordance with CSA Standard CAN 3-A23.2-M77.

* Effective water/cement ratio calculated using only amount of cement passing 45µm sieve.

TABLE D4

CONCRETE MIX PROPORTIONS AND TEST RESULTS ON FRESH CONCRETE

30 Mpa CLASS CONCRETE; AGGREGATE COMBINATION 'B'

I. D.	LAB MIX	BATCH QUANTITIES						TEST RESULTS - FRESH CONCRETE						
		FINE AGG. (kg)	COARSE AGG. (kg)	CEMENT (kg)	WATER (TOTAL) (kg)	WR (ml)	AEA (ml)	SLUMP (mm)	AIR CONTENT (%)	DENSITY (kg/m^3)	YIELD (m^3)	CEMENT CONTENT (kg/m^3)	EFF. W/C RATIO (tot. cement)	EFF. W/C* RATIO (cem.pass.45µm)
A	L-709/85	32.5	56.8	17.75	8.30	78.3	1.1	80	6.4	2279	0.0507	351.1	0.4381	0.528
B	L-753/85	32.5	56.8	17.75	8.45	78.3	1.1	85	6.9	2271	0.0509	349.7	0.4409	0.472
C	L-751/85	32.5	56.8	17.75	8.85	78.3	1.1	90	5.6	2300	0.0504	353.2	0.4635	0.573
C1	L-864/84	34.3	56.8	17.75	9.55	78.3	1.4	85	5.9	2300	0.0515	345.6	0.5029	0.585
C2														
D	L-733/85	32.5	56.8	17.75	8.60	78.3	2.1	80	5.5	2296	0.0504	353.2	0.4493	0.474
E	L-743/85	32.5	56.8	17.75	8.20	78.3	3.6	80	5.6	2325	0.0496	358.9	0.4269	0.492
F	L-701/85	32.5	56.8	17.75	8.60	78.3	1.4	90	6.2	2293	0.0505	352.5	0.4494	0.493
G	L-703/85	32.5	56.8	17.75	8.00	78.3	1.1	80	6.0	2300	0.0500	356.0	0.4157	0.483
H	L-735/85	32.5	56.8	17.75	8.95	78.3	2.1	80	6.6	2271	0.0511	348.3	0.4691	0.551
I	L-705/85	32.5	56.8	17.75	8.80	78.3	0.2	80	5.9	2300	0.0504	353.2	0.4606	0.488
J	L-711/85	32.5	56.8	17.75	8.40	78.3	4.3	80	6.6	2311	0.0508	350.4	0.4382	0.493
J1	L-858/84	34.3	56.8	17.75	8.95	78.3	3.5	85	6.3	2282	0.0516	345.0	0.4691	0.512
J2	L-856/84	34.3	56.8	17.75	8.40	78.3	3.0	80	5.4	2311	0.0508	350.4	0.4382	0.480
K	L-741/85	32.5	56.8	17.75	8.50	78.3	2.1	75	5.8	2307	0.0501	355.3	0.4439	0.498
L	L-719/85	32.5	56.8	17.75	8.70	78.3	1.4	75	6.0	2286	0.0507	351.1	0.4550	0.475
M	L-758/85	32.5	56.8	17.75	8.35	78.3	1.4	85	6.6	2271	0.0508	350.4	0.4355	0.500
N	L-715/85	32.5	56.8	17.75	8.75	78.3	2.8	85	6.2	2311	0.0501	355.3	0.4579	0.491

NOTES:

1) All tests carried out in accordance with CSA Standard CAN 3-A23.2-M77.

* Effective water/cement ratio calculated using only amount of cement passing 45µm sieve.

TABLE E
RESULTS OF FREEZE/THAW TESTS, 20 Mpa. CONCRETE

I. D. •	AGGREGATE 'A'				AGGREGATE 'B'			
	• CYCLES	LENGTH CHANGE (%)	WEIGHT CHANGE (%)	RELATIVE DYNAMIC MODULUS (%)	•CYCLES	LENGTH CHANGE (%)	WEIGHT CHANGE (%)	RELATIVE DYNAMIC MODULUS (%)
A	312	-0.006	-3.81	93.5	327	+0.014	-0.77	99.7
B	330	+0.012	-0.93	108.0	339	+0.014	-0.47	100.0
C	307	+0.021	-2.67	96.3	339	+0.012	-0.87	99.7
C1	321	+0.024	-3.84	98.8	328	+0.011	-1.56	101.6
C2	325	+0.015	-2.35	98.6				
D	307	+0.017	-1.96	97.1	338	+0.009	-1.41	100.0
E	328	+0.022	-0.78	100.3	338	+0.003	-1.38	100.0
F	336	+0.018	-0.95	107.6	327	+0.017	-0.35	100.3
G	330	+0.017	-0.98	105.7	327	+0.022	-0.58	100.0
H	336	+0.023	-1.60	103.6	338	+0.008	-0.80	100.7
I	327	+0.018	-0.11	100.3	327	+0.008	-0.41	101.0
J	328	+0.031	-1.15	99.4	327	+0.020	-1.35	97.2
J1					328	+0.022	-1.55	99.0
J2					328	+0.018	-1.91	95.7
K	321	+0.017	-3.23	98.8	338	+0.006	-1.07	100.7
L	338	+0.012	-0.91	101.2	338	+0.008	-1.49	100.7
M	336	+0.033	-0.99	103.0	339	+0.012	-1.06	99.7
N	327	+0.017	-0.45	100.6	327	+0.012	-0.78	100.6

NOTES:

1) Tests carried out in accordance with ASTM C666, Proc. A

TABLE F

AIR VOID SYSTEM PARAMETERS: LINEAR TRAVERSE

		I.D. *	AIR CONTENT		VOIDS PER 25mm	SPECIFIC SURFACE mm-1	SPACING FACTOR mm
			FRESH CONCRETE %	HARDENED CONCRETE %			
AGGREGATE COMB. A	20 Mpa	A	6.6	4.1	5.45	21.5	0.237
		B	6.0	5.5	6.58	19.1	0.232
		C	6.4	3.8	5.88	24.5	0.213
		C1	6.0	4.2	5.28	20.3	0.248
		C2	6.5	6.2	6.78	17.3	0.231
		E	5.5	4.7	7.30	24.9	0.192
		F	6.4	4.9	6.73	22.1	0.212
		H	6.0	5.0	6.45	20.5	0.225
		I	6.7	5.5	9.15	26.5	0.170
		J	5.5	4.3	7.55	28.0	0.176
		K	5.4	5.1	6.13	19.3	0.228
		L	6.3	5.4	6.60	19.7	0.221
		N	6.5	5.3	6.75	20.4	0.221
	30 Mpa	A	5.9	3.9	6.65	27.0	0.198
		B	6.2	4.3	6.43	23.8	0.216
		C	6.5	6.8	5.18	12.1	0.326
		C1	5.6	4.2	5.00	19.1	0.272
		C2	5.6	4.5	5.88	21.0	0.240
		E	5.5	5.1	8.10	25.3	0.187
		F	6.2	5.3	6.28	18.9	0.247
		H	6.0	4.9	7.15	23.5	0.207
		I	5.5	4.2	5.33	20.2	0.257
		J	6.3	4.5	8.93	31.9	0.158
		K	5.5	3.6	5.48	24.0	0.231
		L	6.2	4.8	5.83	19.4	0.252
		N	5.4	4.0	5.93	23.6	0.224
AGGREGATE COMB. B	20 Mpa.	A	6.3	6.4	8.83	22.1	0.177
		B	6.8	7.4	11.78	25.6	0.133
		C	6.5	4.7	6.38	21.7	0.219
		C1	6.3	5.7	8.53	23.9	0.183
		E	5.4	6.5	10.25	25.3	0.152
		F	6.4	4.9	6.58	21.6	0.217
		H	6.8	4.9	8.63	28.0	0.167
		I	6.4	5.1	9.43	29.4	0.156
		J	5.6	5.5	10.00	28.9	0.153
		J1	6.7	6.0	10.85	29.1	0.144
		J2	5.5	5.0	7.30	23.5	0.197
		K	6.0	6.4	10.03	25.2	0.156
		L	6.4	5.1	8.73	27.5	0.167
		N	6.4	5.5	8.45	24.4	0.181
	30 Mpa.	A	6.4	6.7	11.13	26.6	0.152
		B	6.9	7.0	13.30	30.4	0.127
		C	5.6	6.0	8.30	22.2	0.199
		C1	5.9	5.0	7.68	24.4	0.196
		E	5.6	5.2	10.40	32.1	0.147
		F	6.2	5.6	7.48	21.4	0.213
		H	6.6	6.4	10.58	26.5	0.159
		I	5.9	6.4	10.18	25.2	0.166
		J	6.6	5.5	11.08	32.1	0.143
		J1	6.3	6.4	12.38	31.0	0.136
		J2	5.4	4.2	9.15	35.0	0.149
		K	5.8	5.6	9.25	26.2	0.173
		L	6.0	5.7	9.45	26.6	0.170
		N	6.2	5.5	8.35	24.4	0.189

NOTES: Air-void parameters were determined using ASTM C457-82a

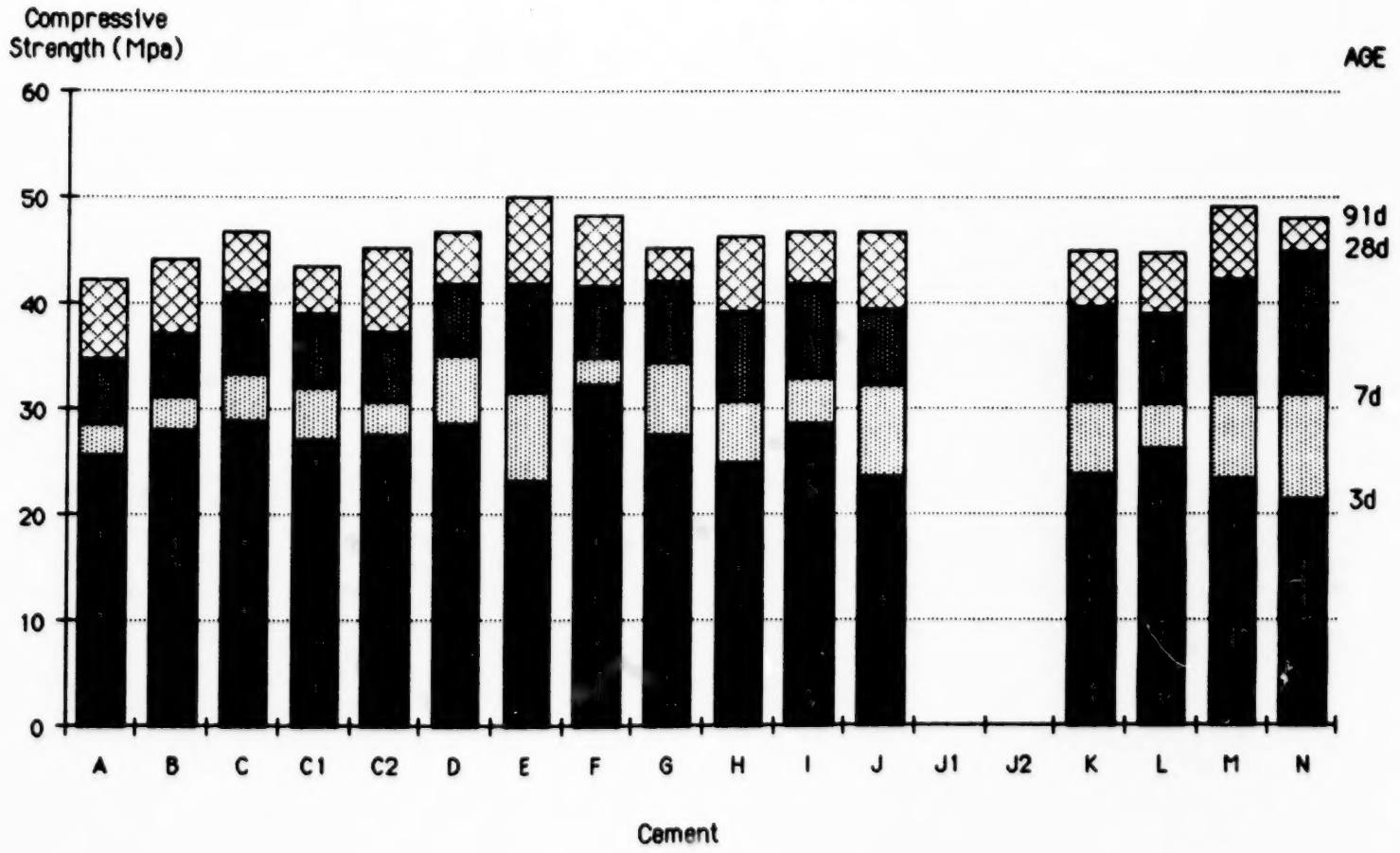

FIG. 1A - COMPRESSIVE STRENGTH (20MPA. AGGREGATE 'A')

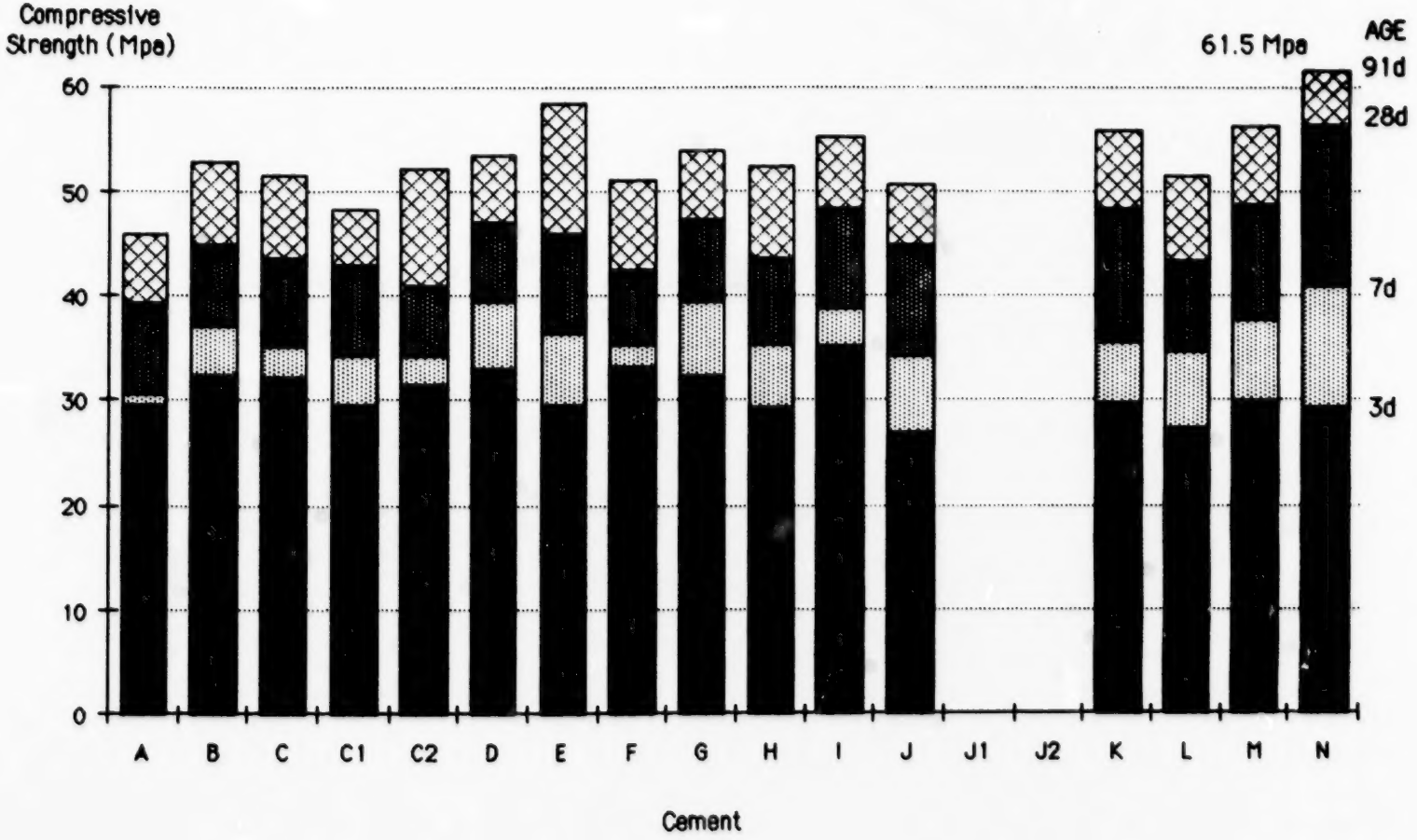

FIG. 1B - COMPRESSIVE STRENGTH (30MPA. AGGREGATE 'A')

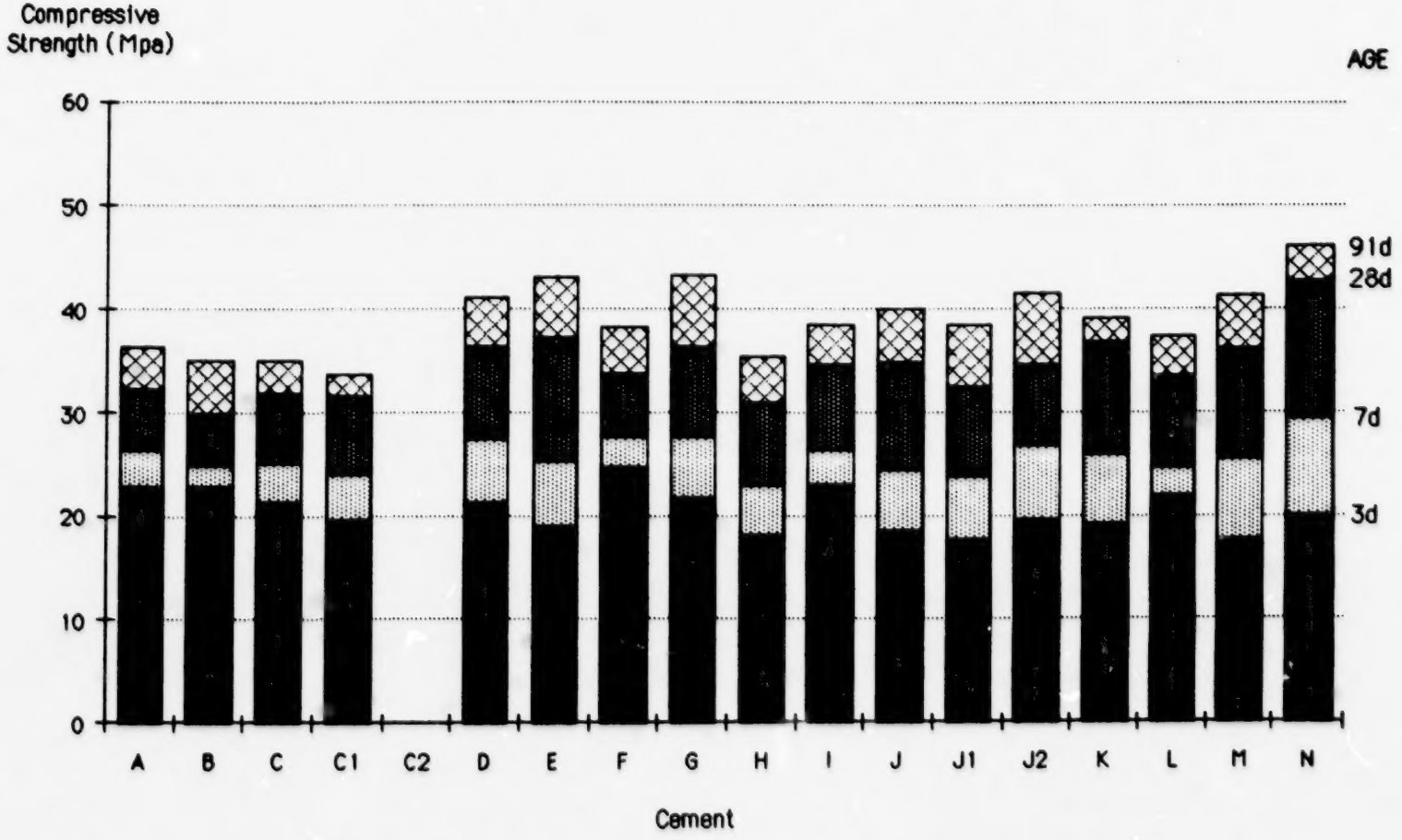

FIG. 1C - COMPRESSIVE STRENGTH (20MPA. AGGREGATE 'B')

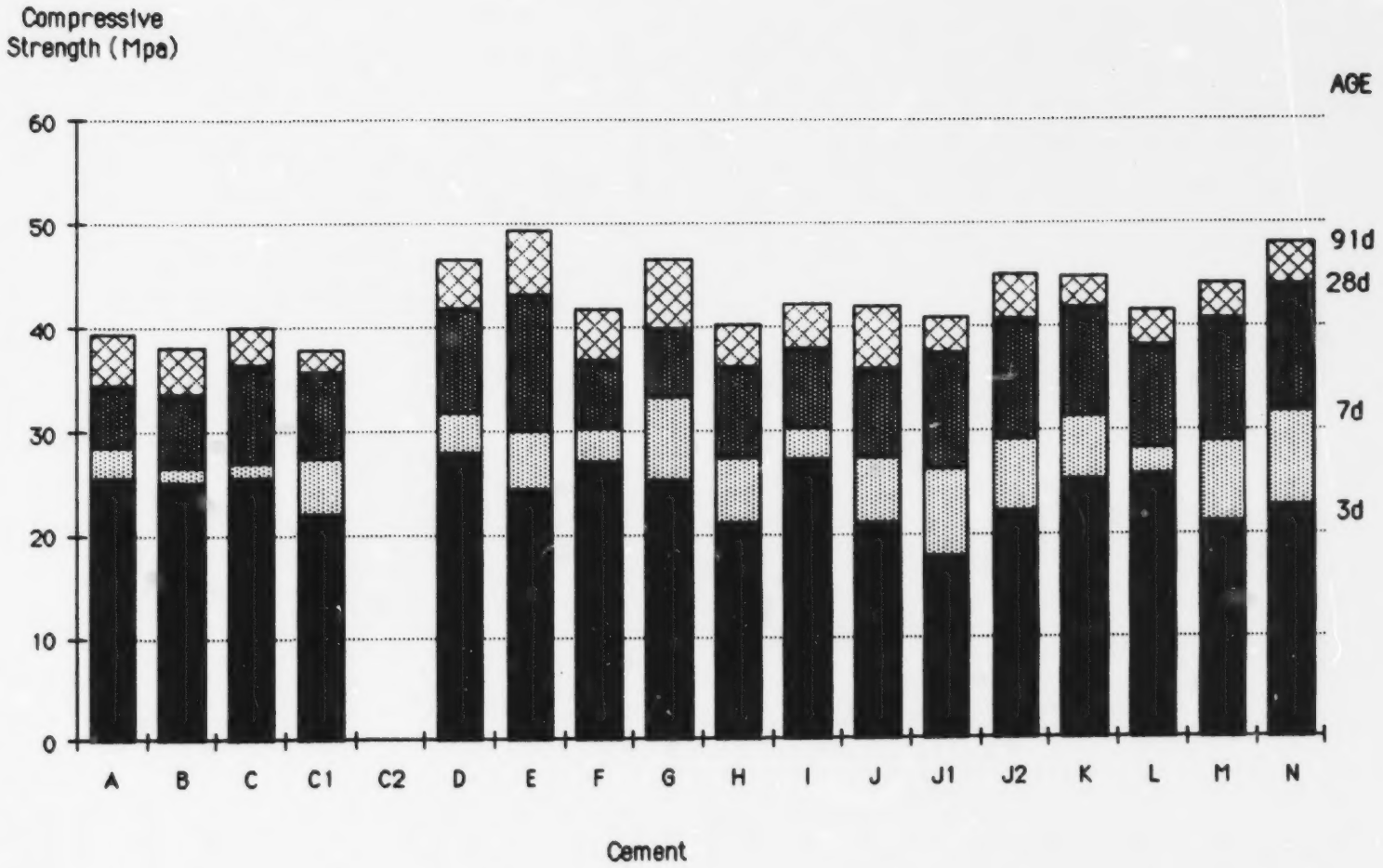

FIG. 1D - COMPRESSIVE STRENGTH (30MPA. AGGREGATE'B')